METEOROLOGICAL FACTORS IN THE QUARTZ CREEK FOREST FIRE

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It is not often that a large forest fire occurs conveniently near a weather station specially equipped for measuring forest-fire weather. The 18,000-acre Quartz Creek fire on the Kaniksu National Forest during the summer of 1926 was close enough to the Priest River Experimental Forest of the Northern Rocky Mountain Forest Experiment Station for the roar of the flames to bring the residents to their doors several times; so close that hose and gasoline-powered pumps were installed to protect the buildings; so close that the women and
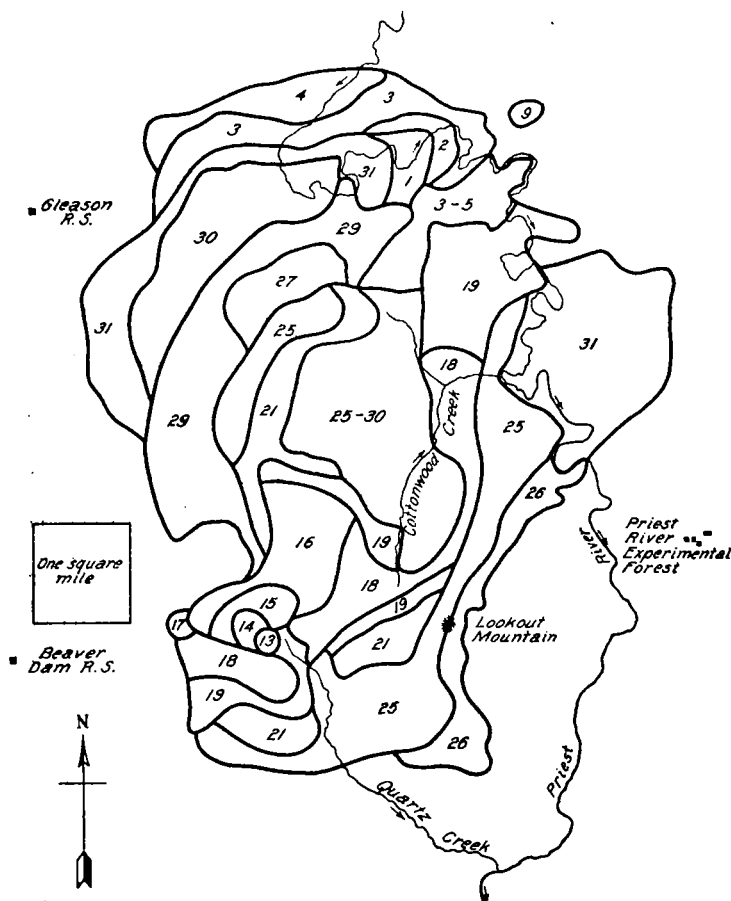

FIG. 1.—Approximate boundaries of burned areas at the close of each day, Quartz Creek fire.

children were sent away to greater safety during the most threatening period. Hence the weather records at the station may indicate some of the reasons for the great spread of this fire.

Figure 1 is a map of the burned area, the heavy lines indicating the boundary of the fire as well as it could be determined at the end of each day. The location of the experiment station buildings and the weather-measuring instruments are indicated near the center of the right-hand edge of the map.

The meteorological equipment at this station includes maximum and minimum thermometers, automatic tipping-bucket rain gage, anemometer, two-magnet register, thermograph, hygrograph, and barograph. Regular measurements are made twice daily of the amount of moisture in the forest duff and in dead branch wood.

This fire in the Quartz Creek drainage started during the early morning of July 13, 1926, being one of the 150 or more forest fires set by lightning storms on July 12 and 13, on the 600,000-acre Kaniksu National Forest. It was discovered and located by the lookouts at 2 p. m. of the 13th. When the first three men reached it two and one-half hours later about 20 acres of timber were ablaze and the fire was already flaring in the crowns of single trees and groups of trees, as well as running rapidly on the ground.

Thirty additional fire fighters were called for immediatly, but, because of the demand created by several hundred other fires in northern Idaho and western Montana, only 12 men came. Further reinforcements were entirely insufficient during the following four days. This lack of men at the start, together with the highly inflammable condition of the fuel, put the fire at the mercy of subsequent weather. The immediate cost and loss to the Federal Government and to the private timberland owners and companies are approximated at $274,000, exclusive of the salvage value of the timber burned.

As indicated by Figure 2, the weather just previous to July 12 had been favorable for extreme inflammability of the forest materials. Rapid evaporation, occasioned by high temperature, high wind, and low relative humidity, had dried out the litter and duff to a moisture content of only 7% on a completely cut-over and fully-exposed area by 5 p. m. July 12. Samples of dead branch wood, 2 inches in diameter, showed the same moisture content. As both these materials retain at least 2 per cent moisture until subjected to sustained temperatures of over 100° F. and relative humidities of less than 10%, it is apparent that at least two of the important forest fire fuels were extremely inflammable. Obviously, the stage was set for a true conflagration.

Rain, usual with electrical storms in this region, amounted to only 0.04 inch with a storm on July 13. It fell between 1:45 and 2:45 a. m. At 8:30 a. m., under full timber canopy in the forest, this light sprinkle had moistened the duff to only 19%, and on clear-cut areas to 36%. The remainder of the day was hot, dry, and windy, and by 5 p. m. the duff moisture in the forest was only 9%, and in the open 6½%. The benefits of the rain were short lived indeed. Not another trace fell until August 16, seven days after this fire was completely controlled; hence the remainder of the story, in so far as the weather is concerned, is largely one of temperature, humidity, and wind.

Investigators have tried various methods to determine the cause-and-effect relationships between the weather elements and the behavior of fires. In some cases they have related the final area of the fire to the maximum temperature, the minimum relative humidity, and the average wind velocity of the day when the fire started. In other cases the maximum temperature, minimum humidity, and daily wind movement have each been averaged for the period of the fire and these averages taken to indicate conditions productive of the total area burned by that fire. A more sensitive method would be to compare the maximum, minimum, and mean temperatures, humidities, and wind velocities for the days when the fire made its biggest runs, with the weather conditions on the other days when the fire was spreading least rapidly.

Such a method encounters a great difficulty, however, in the lack of accurate information concerning the size of the fire at the end of each day. Only rarely and through special effort can maps be made to show the fire front locations day by day, and even those have an error which must be assumed as considerable because the maps are necessarily based on hasty observations along a fire front perhaps 15 or 20 miles in length, these being harmonized as well as possible in the circumstances. It is also desirable to distinguish the trenched and controlled front from the untrenched or uncontrolled, in

explaining some of the cause-and-effect relationships exhibited by the fire.

In such investigations it is usually good practice to consider first the variations of the effect and then to determine which of their probable causes were most important. One of the major peculiarities of the Quartz Creek fire was its direction of spread. As shown by Figure 1, 87% of the area burned lies north of the point of origin of the fire and 57% northeast of it. As the bulk of these areas is at approximately the same or even a lower elevation than the source, it is obvious that this
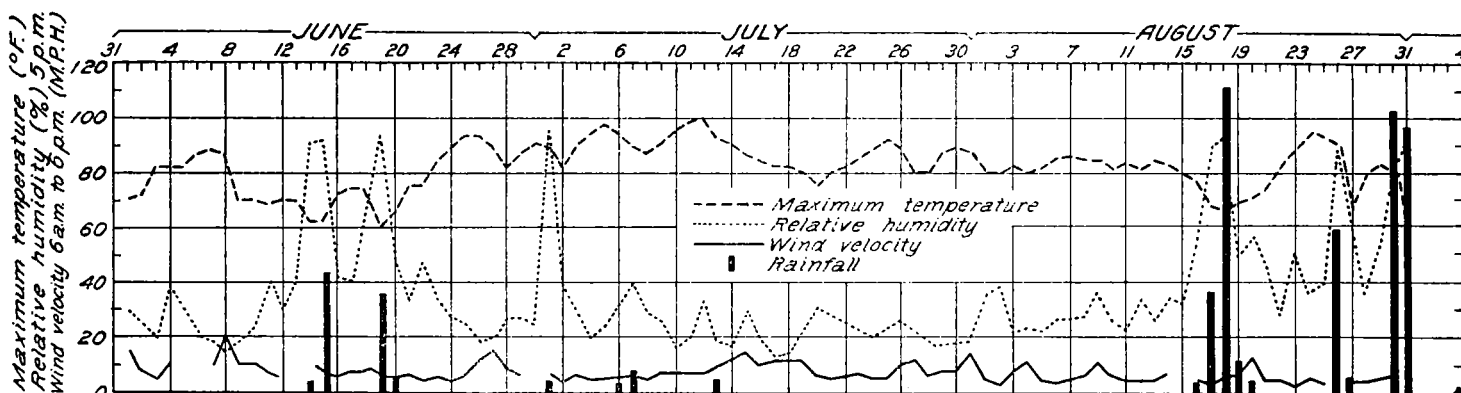

FIG. 2.—March of certain weather elements at the Priest River Experimental Forest, May 31–August 4, 1926

order to follow accurately the growth of the fire each day. Maps prepared by the airplane observers might be of considerable assistance in this respect, but a big and very active fire sometimes prevents close scrutiny even from an airplane.

Choice of a unit for measuring change of size of the fire offers a second difficulty. The area burned over and the length of the fire front are the two most usable units, but both have obvious disadvantages. It would seem that either one should be satisfactory, but as can be seen from Figures 1 and 3, the Quartz Creek fire increased from 8,000 acres on July 25 to 13,600 acres on July 30, yet its perimeter was decreased from 27 miles to 25 miles by that very growth, through the burning out of holes or pockets in the fire so that its exterior boundary was reduced nearer to circular form. It is rather startling to think that a fire can increase 5,600 acres in area, yet have two miles less perimeter as a result. The fact that this did occur indicates, among other things, the need for careful consideration before deciding whether area or perimeter should be used as a criterion of the effects of the weather elements.

Another very important factor influencing growth and ultimate size of the fire is the opposition to spread offered by the fire-fighting organization. This opposition is somewhat independent of the weather. If maps were available showing the location and length of held line—or suppressed fire front—each evening, as distinct from the location and length of the uncontrolled fire front, it might be possible, by isolating this factor to some extent, to determine more accurately the effects of the weather alone on the fire's growth. Unfortunately such a refined map is not obtainable for the Quartz Creek fire, and can not be obtained for very many fires because of the great difficulty involved. Study of a fire has to be incidental to the main job since frequently the man making the study will be forced to drop his observations and help where he can on the fire line. The few observations obtainable aid, nevertheless, in

great spread can not be charged to greater ease of spread of fire uphill or to topography. As the fuels were no more favorable to the north than to the south, the very uneven spread likewise was not due to timber or fuel types. As temperature and humidity undoubtedly were similar throughout the area, the uneven spread can not have been due to these factors. Most of the suppression work of the first few days was concentrated on the south side of the fire, but the northward-spreading head was not neglected.

There remains, of the atmospheric elements affecting spread, the wind. The records at the experiment station
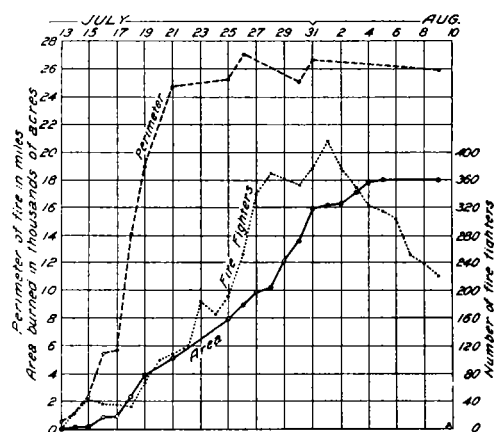

FIG. 3.—Daily changes of area, perimeter and number of fire fighters during the Quartz Creek fire

forest show that the wind was southwest 22 days out of the 28 during which this fire burned. The wind blew toward the northeast 79% of the time; and, as stated above, from 57% to 87% of the area burned was northeast and north of the point of origin. One effect of wind is obvious: As the fire was stopped only 5 miles south of the point of origin, but about 21 miles north of it the

very great importance of wind direction in the spread of a fire over ground of moderate relief is indicated.

The southward spread of this fire was mostly uphill; therefore the exact effect of the wind upon it is difficult to determine. It is worth noting, however, that on July 21 when there were two marked runs to the south and one to the north, the wind was from the north. It is clear that the direction of the prevailing wind (from the southwest in this region) is very significant, as are also the daily shifts of wind direction. In the case of this fire the northerly winds of July 21 were predicted accurately on the 20th by the U. S. Weather Bureau, and the forecast supplied immediately to most of the men in charge of crews.

Probably the second most important variation in the behavior of this fire lies in the big runs on a few days. Of the 18,000 acres burned over during 28 days, 9,600 acres went up in smoke on 7, July 18, 19, 26, 27, 29, 30, and 31. It is believed that a large area was also burned over on the 25th, but it has not been possible to obtain a map of the fire boundary for the evening of July 24, hence no certain deductions can be drawn for the 25th. Nevertheless, the fact that 53% of the area was burned in 25% of the time indicates that certain factors must have been more favorable for rapid spread on these few days. From the standpoint of area burned it is apparent that 1,370 acres were burned on the average bad day and only 400 acres on the average of the other days. It might be profitable to find out how the weather on these bad days differed from that on the others.

The weather records obtained at the experimental forest, less than two miles from the edge of the fire, show the conditions for each day (Table 1).

TABLE 1

Days	Area burned, acres	Temperature		Relative humidity		Average wind velocity			
		Maximum	Minimum	Maximum	Minimum	Afternoon, noon–6 p. m.	Day, 6 a. m.–6 p. m.	Night, 6 p. m.–6 a. m.	24-hour average, 6 p. m.–6 p. m.

EASY DAYS

			° F.	° F.			m. p. h.	m. p. h.	m. p. h.	m. p. h.
July	13	20	90	57	98	12	11.5	9.1	3.5	6.3
	14	130	86	45	92	15	12.3	10.8	2.9	6.9
	15	100	78	44	82	24	14.0	14.0	5.4	9.7
	16	700	82	43	90	19	11.3	8.9	2.5	5.7
	17	50	81	38	88	10	12.8	10.4	2.6	6.5
	20	¹ 650	73	45	76	25	6.0	5.0	4.2	4.6
	21	¹ 650	78	37	94	18	5.2	4.2	2.6	3.4
	22	¹ 700	80	41	87	25	5.7	4.6	4.9	4.8
	23	¹ 700	84	43	95	20	6.8	6.0	1.9	4.0
	24	¹ 700	89	43	90	19	6.0	5.2	1.9	3.6
	25	¹ 700	92	47	87	19	6.8	5.3	2.5	3.9
	28	300	80	37	82	14	6.3	5.2	1.7	3.5
Aug.	1	200	75	39	75	22	3.2	4.3	3.8	4.0
	2	200	78	28	88	23	2.2	2.2	2.4	2.3
	3	800	81	37	97	21	10.5	7.1	2.2	4.7
	4	700	77	40	94	22	13.2	10.9	2.1	6.5
	5	100	80	39	90	19	4.8	3.8	2.6	3.2
	6	¹ 25	85	39	92	14	4.2	2.7	1.9	2.3
	7	¹ 25	86	40	88	18	6.2	4.6	2.4	3.5
	8	¹ 25	84	45	90	25	8.8	6.4	2.2	4.3
	9	¹ 25	76	47	92	35	12.0	11.0	2.5	6.8

¹ Total for several days apportioned to each day of the period.

BAD DAYS

July	18	1,300	81	35	84	13	15.0	11.2	2.5	6.8
	19	1,600	72	48	65	22	16.0	9.7	8.2	8.9
	26	1,000	82	50	86	24	16.5	9.7	4.0	6.8
	27	▮ 900	73	51	60	25	10.2	11.0	6.2	8.6
	29	2,000	86	38	84	14	9.6	7.2	2.2	4.7
	30	1,400	88	42	94	15	10.8	7.4	2.2	4.8
	31	2,300	82	44	77	18	14.2	13.1	3.0	8.0

For all 28 days the conditions averaged as follows:

TABLE 2

Temperature: Average maximum, 81.6°; average minimum, 42.6°; average mean, 61.9°.

Relative humidity: Average maximum, 86.3%; average minimum, 19.7%; average mean, 53.0%.

Wind velocity: 6 p. m. to 6. a. m., average 3.1 miles per hour; 6 p. m. to 6 p. m., average 5.3 miles per hour; 6 a. m. to 6 p. m., average 7.5 miles per hour; Noon to 6 p. m., average 9.0 miles per hour.

The average temperatures were based on hourly temperatures from the thermograph records. The humidity averages are from the hygrograph records, checked against the sling psychrometer at least once each afternoon and very accurate for the lower humidities, but admittedly somewhat erratic for the higher. The wind velocities are the averages for the full hours specified, as recorded by the two-magnet register for the anemometer 150 feet above the ground, and 75 feet above the tops of surrounding trees.

A compilation of the records for the seven bad days shows that on these days the wind velocity was above the average for the duration of the fire, regardless of whether the afternoon wind, the daylight wind, the nighttime wind, or the average for 24 hours is considered. This is shown in tabular form as follows:

TABLE 3.—Average wind velocity in excess of normal in miles per hour

Average	6 p. m. to 6 a. m.	6 p. m. to 6 p. m.	6 a. m. to 6 p. m.	Noon to 6 p. m.
21 easy days	2.8	4.8	6.7	8.1
28 days	3.1	5.3	7.5	9.0
7 bad days	4.0	7.0	9.9	11.5

This arrangement of the data also brings out the fact that the nighttime wind was least dangerous and the noon to 6 p. m. velocity was nearly three times as great. It also indicates the need of forecasts of the daytime or better yet for the afternoon wind rather than the average for the 24-hour period. Few, if any, of the big runs made by the Quartz Creek fire occurred at night; nearly all were in the afternoon when the wind was at its worst. Regardless of temperature or humidity, it is obvious that the 7 days of greatest spread were marked by average wind velocities appreciably greater than on the other 21 days.

The records of relative humidity indicate a small but perhaps significant effect of this weather element in contributing to the big runs, as follows:

TABLE 4.—Average relative humidity

Average	Maximum	Minimum	Mean
	Per cent	Per cent	Per cent
21 easy days	88.9	20.1	54.5
28 days	86.3	19.7	53.0
7 bad days	78.6	18.4	48.5

The greatest difference here is found in the maximum humidity. This finding is in accordance with that of M. E. Dunlap, of the Forest Products Laboratory, through laboratory tests, indicating that a small change in the higher humidities causes a fairly large change in fuel moisture content, whereas a relatively large change

in the lower humidities produces a comparatively small change in fuel moisture. The fact that the minimum humidities did not vary greatly on the 7 bad days from the average for the 21 easy days further corroborates this conclusion. As previously stated, however, although the hygrograph used in studying the Quartz Creek fire was very accurate for the lower humidities, it was variably inaccurate at humidities of over 70%, hence perfect dependence can not be placed upon these variations of maximum humidity. About the only conclusions that can be drawn safely are that the average maximum humidity was 10% lower and the average minimum 2% lower on the bad days than on the days of least rapid spread, and that lower humidity probably contributed to the big runs of the fire.

The variations of temperature, the last weather factor to be considered, show no great agreement with the marked variations of this particular fire. The following averages were obtained from Table 1 in the same way as those previously given for relative humidity:

TABLE 5.—*Average temperature in °F.*

Average	Maximum	Minimum	Mean
	Per cent	Per cent	Per cent
21 easy days	81.7	42.1	61.9
28 days	81.6	42.6	61.9
7 bad days	80.6	44.0	62.3

In this case only the average minimum temperature was materially higher on the 7 bad days than on the 21 easy ones. The average maximum temperature is shown to have been 1.1° lower on the bad days, instead of higher, than on the easy ones. It is undoubtedly justifiable to conclude that neither maximum nor minimum temperature variations were of any great importance in controlling the spread of the Quartz Creek fire.

It should be noted that this conclusion applies to. *variations* of temperature. From another viewpoint, that of the average temperature and humidity, both were undoubtedly of great importance in controlling the rate of spread and the ultimate size of the fire. As has been shown, the average maximum temperature for the duration of the fire was approximately 82° and the average minimum humidity about 20%. From Dunlap's study of the equilibrium relations between certain fuel moisture contents and temperature and humidity, it is known that if forest duff, twigs, slash, etc., are subjected to an atmosphere having a sustained temperature of 80° and a relative humidity of 20% the fuels will have a resultant moisture content of about 5%. For a sustained condition of 62° F. and 53% humidity, the means previously given, the equilibrium moisture content is about 10%. As 10% moisture in either wood or duff has been found by experiment to mean high inflammability and as 5% moisture content implies extremely dangerous dryness, it is obvious that the average temperatures and humidities during the Quartz Creek fire were sufficiently high and low, respectively, to favor very rapid spread of the fire. During the nights, when the average minimum temperature was 43° and the average maximum humidity was 86%, the fuels would have picked up moisture to a theoretical average amount of 20%, and only then should they have been appreciably less favorable to rapid spread of fire regardless of the wind.

Measurements made with the duff hygrometer show that the average duff moisture content was 13% at 8.30 a. m. and 7% at 4.45 p. m. on the fully exposed area during the days of the fire. The mean of these two is 10%, the same as deduced above on the basis of Dunlap's laboratory work. The differences between 13% and 20% and between 7% and 5% are attributed to the fact that sustained and constant temperatures and humidities were assumed in the theoretical deduction of the effects of these two weather elements on duff moisture. Actually, however, both temperature and humidity varied rapidly, and as duff moisture does not respond instantly to such changes, and as the mineral soil beneath the duff affects the fuel moisture, an appreciable lag is to be expected. The actual measurements of duff moisture therefore appear to agree with the theoretical deduction in showing that temperature and humidity combined to produce very dry fuels, which in turn favored rapid spread of fire throughout the 28 days under consideration.

CONCLUSIONS

The writer believes there is need of an accurate map of the controlled and uncontrolled fire front at the close of each day, so that the effects of suppression measures can be isolated, and so that area burned and perimeter of the fire can be computed for comparison with each of the important weather elements. In the present case the map shown was obtained primarily as an aid in studying the tactics of fire suppression actually used, and those that might better have been used.

It is apparent that with such a map the relative importance of certain weather factors can be roughly determined. In the present case it was found that mean temperatures of 62° F. or more, combined with mean relative humidities of 53% or less, occurring when the forest duff and branch wood have already dried out to less than 10% moisture content, implies a fuel condition conducive to very rapid spread of fire. Such conditions evidently warrant special preparedness in the future. It is further apparent that the big runs of a fire, under the above conditions, are influenced chiefly by wind direction and velocity; secondly, by small changes in relative humidity; and least of all by minor temperature changes. Forecasts of a 24-hour average wind velocity of 7 miles per hour should be recognized as implying much greater danger than forecasts of an average velocity of 4.8 or 5 miles per hour. As soon as possible the predictions of wind velocity should be refined to apply only to the daylight hours, and preferably to distinguish the afternoon hours. Indications for the occurrence of average maximum, minimum, and mean temperatures and humidities, such as those shown for the seven bad days of the Quartz Creek fire, likewise should be met with special preparedness.

The accuracy in later application of all of these findings is contingent upon similar conditions of fuels, topography, and fire suppression technique, all of which are admittedly important factors not considered in detail by the present study.

Another fact, of importance to all students of fire behavior, is the need of rather elaborate meteorological equipment which will provide graphic records of the weather elements. It should be obvious that irregular or infrequent measurements of temperature, humidity, and wind could not have been used in this study as easily as the continuous records. As large fires close to well equipped weather stations are not of common occurrence, it is altogether probable that special instruments must be developed which can be transported to the vicinity of large fires if much work similar to the present is to be conducted.

Clearly, an investigation of a single fire provides only a small fraction of all the evidence that must be accumulated before thoroughly dependable conclusions can be drawn. Other fires, under similar conditions of temperature, humidity, and wind, might exhibit entirely different behavior if the fuels, the topography, or the

tactics of suppression differed materially. Several of these investigations must be made in each distinct timber type under different weather conditions before the major variations of fire behavior can be accurately related to the behavior of the weather.

INVESTIGATION OF RAINFALL PERIODICITIES BETWEEN 1 1/6 AND 2 1/2 YEARS BY USE OF SCHUSTER'S PERIODOGRAM

By Dinsmore Alter

[University of Kansas, Lawrence, Kans., December, 1926]

SYNOPSIS

The present paper continues previous applications of Schuster's periodogram to the rainfall of the world, in this case for shorter periods than considered in them. The evidence continues favorable, and is even stronger than before, in favor both of the existence of what may be termed a "spectrum" of related periods and of their relation to the sun-spot period. It also begins to differentiate strongly between fairly constant periods and variable cycles, in favor of the former.

This paper and a short investigation of economic values of statistical examinations of rainfall periodicities to be published in the next issue of this REVIEW, complete a series of studies (1) of the rainfall of the world, begun about seven years ago. In these it was concluded definitely that periods or cycles do exist, but whether of constant length and amplitude remained uncertain.

The last few papers have been an application of Schuster's periodogram to these data and a study of the method itself. In each paper a stretch of shorter periods than the preceding ones has been considered.

Since Schuster's (2) original papers are available and also the preceding papers of this series which considered the method in detail, it is unnecessary to explain the method.

Given data q_1 _____ q_n, assume any period P_j times the datum interval. Let φ_i be the phase angle for the datum q_i so that

$$\varphi_{i+1} - \varphi_i = \frac{2\pi}{P}$$

$$\varphi_1 = 0$$

$$A_j = \sum_1^n q_i \cos\varphi_i$$

$$B_j = \sum_1^n q_i \sin\varphi_i$$

$$I_j = \frac{A^2_j + B^2_j}{n}$$

and is proportional to the square of the amplitude of the best sine curve of period P_j to fit the data.

$$\tan\Phi_j = \frac{B_j}{A_j}; \quad I_{mean} = \frac{\sum_1^n \sigma^2_i}{2(n-1)}.$$

Where σ_i is the deviation of q_i from the mean q.

$$H_j = \frac{I_j}{I_{mean}}; \quad I'_j = I_j \frac{(x-y)^2}{4\sin^2\frac{1}{2}(x-y)}.$$

where X is the phase of q_i and Y that of $q_i + 1$ in radian measure. I' is the value of I which would have been secured had much shorter datum intervals been used.

I not I' must be used in computing the probability of securing any given I by accident.

In this paper semiyearly rainfall means from the Pacific coast of the United States, from the Punjab and from the British Isles are used. These data, in the form of percentage departures from normal, are given as Table 1. The periods computed overlap those of the preceding paper. First, periodograms for periods between $1\frac{1}{16}$ and $2\frac{1}{2}$ years are computed from each half of the data of each of these sections. These chronologically independent periodograms are then compared. Finally a periodogram is computed from the total data of each section and conclusions drawn.

Before comparing these chronologically different periodograms a few points respecting the evidence given by periodograms may be considered.

(a) The fact that the peaks of chronologically different periodograms are of different intensity or of slightly different position is often considered as indicating variability of period. On page 480 of the October, 1924, MONTHLY WEATHER REVIEW are two very different appearing periodograms, made from different long stretches of data, composed by the addition of two sine curves of equal amplitude. When it is remembered that in these data there were only two periods and no accidental errors at all, the possibilities of variation, where the data may be composed of a whole spectrum of periods plus large accidental errors, are seen to be great enough almost to preclude evidence in favor of a variable cycle unless a very great number of such cycles have been completed.

(b) The comparison of periodograms by Pearson's correlation coefficient, while useful, minimizes the relationship between them for the following reasons:

1. Suppose that in the periodograms one real peak is shown equally in both. This one peak will give a positive correlation but all the rest will give a zero correlation, since the theory of the periodogram shows that it varies under the accidental error law, except in the vicinity of real periods. We would, therefore, in this case, expect from the periodograms a small positive coefficient, comparable with the probable error, and telling us, therefore, little or nothing. *A large positive correlation becomes strong evidence, consequently, in favor of a whole spectrum of real periods even where the separate peaks may be too low in height to carry much weight individually.*

2. If there are variable cycles, or if the interference of periods, or the accidental errors, have produced slight shifts in the positions of peaks, the two periodograms will give a negative coefficient, sometimes very large. This is beautifully illustrated in the periodograms of the Pacific coast. At about 2.30 years a high peak starts in each. At about 2.33 years the one from the early data reaches its maximum $H = 4.8$, here exactly coinciding with the later periodogram. This later one continues to rise to $H = 10.5$, while the earlier one falls rapidly. One half indicates a period at $P = 2.33$ years, the other at $P = 2.44$,